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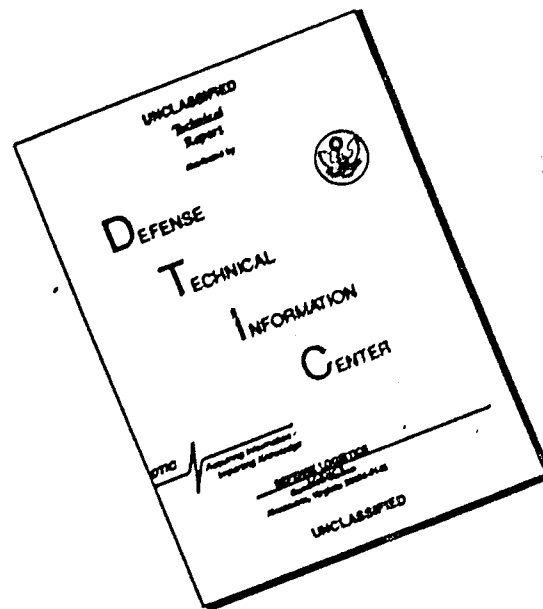
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REPORT NO. 710/275

TEST OF LAMINATED THIN ARMOR PLATE

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WATERTOWN ARSENAL, WATERTOWN 72, MASS.

By

E. L. REED
Research Metallurgist

S. L. KRUEGEL
Jr. Phys. Science Aide

DECEMBER 15, 1938

WATERTOWN ARSENAL
WATERTOWN, MASS.

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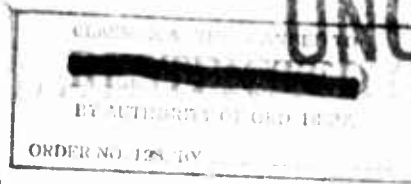
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Report No. 710/275
Watertown Arsenal

December 15, 1938

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TEST OF LAMINATED THIN ARMOR PLATE

Ref: A.P.G. Report, June 14 & 16, 1938,
Firing Record 11392,
O.O. File 470.5/2382
A.P.G. File 470.5/400.1

Purpose

The purpose of this investigation was to study the relative ballistic efficiencies of the four types of laminated plates when tested with caliber .50 A.P. M1 and 37 mm. A.P. M39 ammunition.

Conclusions

1. The sections built up with commercial steel backing had about the same ballistic limit as the sections built up with heat treated armor plate.
2. The ballistic limit of this particular laminated plate was generally 300 feet per second lower than the homogeneous plate of the same thickness.

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3. Although the plates heat treated at Watertown Arsenal were reported as having a Brinell Hardness of 401/429, hardness surveys after ballistic test revealed that the true hardness was 444/477, a value much too high to expect good ballistic properties under 37 mm. impact.

Method of Procedure

Four laminated sections of light armor plate were made at Watertown Arsenal, which sections are shown in Figures 1 - 4 and are described as follows:

	<u>Front</u>	<u>Center</u>	<u>Rear</u>
a. Section L - 12x12x1-3/16"	1/2" A.P.	1/8" Dural	9/16" Ni-Mo Steel
b. Section L-1- 12x12x1-1/4"	1/2" A.P.	1/8" Dural	1/2" Ni steel
c. Section L-2- 36x36x1"	3/8" A.P.	3/16" Dural	3/8" A.P.
d. Section L-3- 36x36x1-1/4"	1/2" A.P.	1/4" Dural	1/2" A.P.

All sections had 1/32" clearance between the Duralumin plate and rear face.

Items a and b were made with armor plate for the front face and commercial welding steels for the rear face, and then tested with caliber .50 A.P. M1 ammunition.

Items c and d used armor plate for both front and rear faces and were tested with caliber .50 A.P. M1 and 37 mm. A.P. M39 ammunition.

Ballistic tests were made at Aberdeen Proving Ground.

All armor plates were heat treated at Watertown Arsenal to a Brinell Hardness of 401/429.

Microscopic examination was made on the heat treated plates for the purpose of controlling the carbide condition.

Results of Investigation

Chemical Analysis

The chemical analysis of the armor plate facing and the commercial welding steels is given in Table 1, as follows:

<u>Material</u>	<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>S</u>	<u>P</u>	<u>Ni</u>	<u>Cr</u>	<u>Mo</u>	<u>Va</u>
Armor Plate	.46	.57	.305	.018	.012	-	1.16	.70	.25
Ni-Mo Steel	.22	.89	.225	.018	.021	2.74	.08	.36	-
Nickel Steel	.335	.53	-	.029	.013	3.27	-	-	-

Heat Treatment

Plate L - Heated to 1600°F for 2 hours, oil quenched and drawn at 925°F for 2 hours and air cooled.

Plate L-1 - Heated to 1600°F for 2 hours, cooled to 1450°F, held 1/2 hour, oil quenched and drawn at 925°F for 2 hours and air cooled.

Plates L-2 and L-3 - Heated to 1650°F for 2 hours, oil quenched and drawn at 925°F for 2 hours and air cooled.

Microscopic Study

The microstructures of the heat treated plates were studied and typical structures are shown in Figure 14.

Brinell Hardness

Brinell hardnesses of the plates are given below:

(a) Brinell Hardness As Reported after Heat Treatment:

L-, L2 and L3 - 429
L-1 - 401

(b) True Brinell Hardness - Taken on Cross Section of Plate:

	<u>Edge</u>	<u>Center</u>
L	477	477
L-1	477	477
L-2	444/460	444
L-3	444/460	477

Discussion

The tests of Watertown Arsenal laminated plates by Aberdeen Proving Ground are not conclusive since the Brinell hardness was too high, although the hardness reported after heat treatment was typical of good quality armor plate. However, in taking these readings, insufficient material must have been removed from the decarburized surface since hardness readings made on sections cut from the interior of the plate after firing showed the actual hardnesses to be 444/477.

Table 2 indicates that a commercial steel backing is as effective in resisting penetration by caliber .50 A.P. M1 ammunition as an armor plate backing.

The laminated plate was not as efficient ballistically as a solid plate of the same weight. Table 3 shows a comparison of weights and ballistic limits.

The 1/2" armor plate used for facing, since it had such a high hardness, would undoubtedly have spalled if tested individually with caliber .50 A.P. ammunition. Thus, some advantage was gained in that no spalling occurred in the laminated section.

Better results can be expected from plate with a Brinell hardness of 400/418 on 37 mm. solid shot tests.

Figures 1 to 3, inclusive, give the construction plan for each laminated plate.

Figures 4 to 13, inclusive, illustrate the condition after ballistic test of the front and rear faces of some of the laminations which made up two sections, namely, L and L-3.

Figure 14 illustrates the microstructure of heat treated armor plate used in the construction of laminations.

Respectfully submitted,

E. L. Reed.

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Research Metallurgist.

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TABLE 2

Plate No.	Total Thickness In Inches	Construction	*Specified Ballistic Limit			*Specified Ballistic Limits of Solid Plate of Same Thickness as Laminated Plate (Cal. 37 mm., A.P. 1.45 lb.)		
			Ballistic Limit with Cal. .50 A.P.	Spalling Characteristics on Cal. .50 A.P.	Spalling Characteristics of Solid Plate of Same Thickness as Laminated Plate (Cal. .50 A.P.)	Ballistic Limit with 37 mm., 1.45 lb. Solid Shot	Spalling Characteristics with 37 mm. Solid Shot	
							Front	Rear
2	1"	3/8" A.P. 3/16" Dural 3/8" A.P.	2237 ft/sec.	No spall.	2700 ft/sec.	976 ft/sec.	Crack near edge.	Pieces blown out.
1	1-3/16"	1/2" A.P. 1/8" Dural 9/16" Ni-Mo	2586	No spall.	2850			1835
1	1-1/4"	1/2" A.P. 1/8" Dural 1/2" Ni	2566	No spall.	2900			1895
3	1-1/4"	1/2" A.P. 1/4" Dural 1/2" A.P.	2589	No spall.	2900	1272	Cracks	Piece blown out.

Values for thickness greater than one inch are extrapolated from Specification AXS54-K-1; for one inch they are as of Specification AXS54-K-1.

TABLE 3

Plate No.	Total Thickness	Thickness of Solid Plate with Approximately the Same Ballistic Limit	Weight of Laminated Plate	Weight of Solid Plate with Approximately the Same Ballistic Limit	Ballistic Limit With Cal. .50 A.P. f/s. Laminated Plate
L-2	1"	11/16" (36 x 36)	301 lbs.	253 lbs.	2237
L	1-3/16"	7/8" (12 x 12)	42.7 lbs.	35.7 lbs.	2586
L-1	1-1/4"	7/8" (12 x 12)	42.7 lbs.	35.7 lbs.	2566
L-3	1-1/4"	7/8" (36 x 36)	401 lbs.	321 lbs.	2589

FIG. 1

Plan of L and L-1

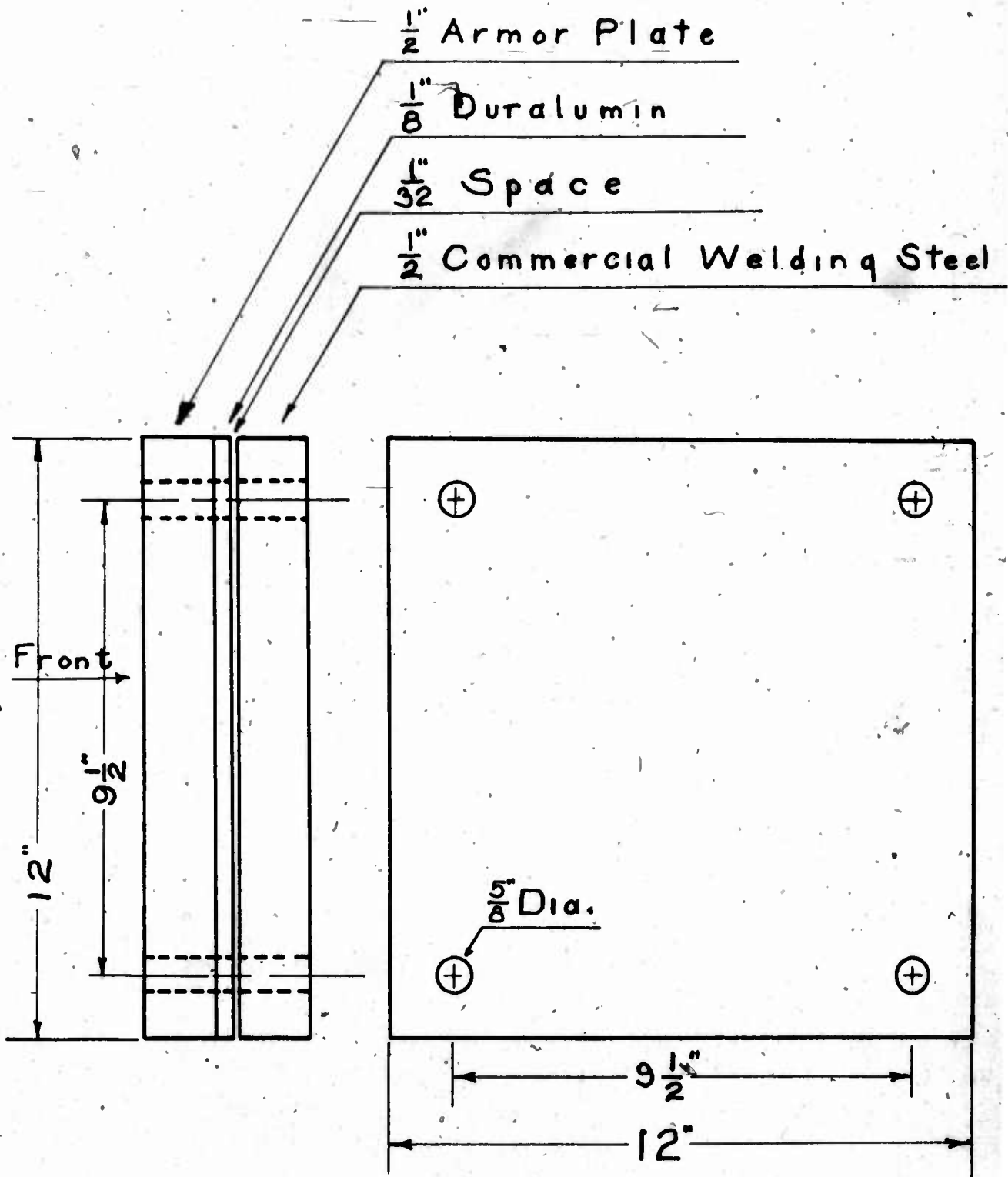


FIG. 2

Plan of L2

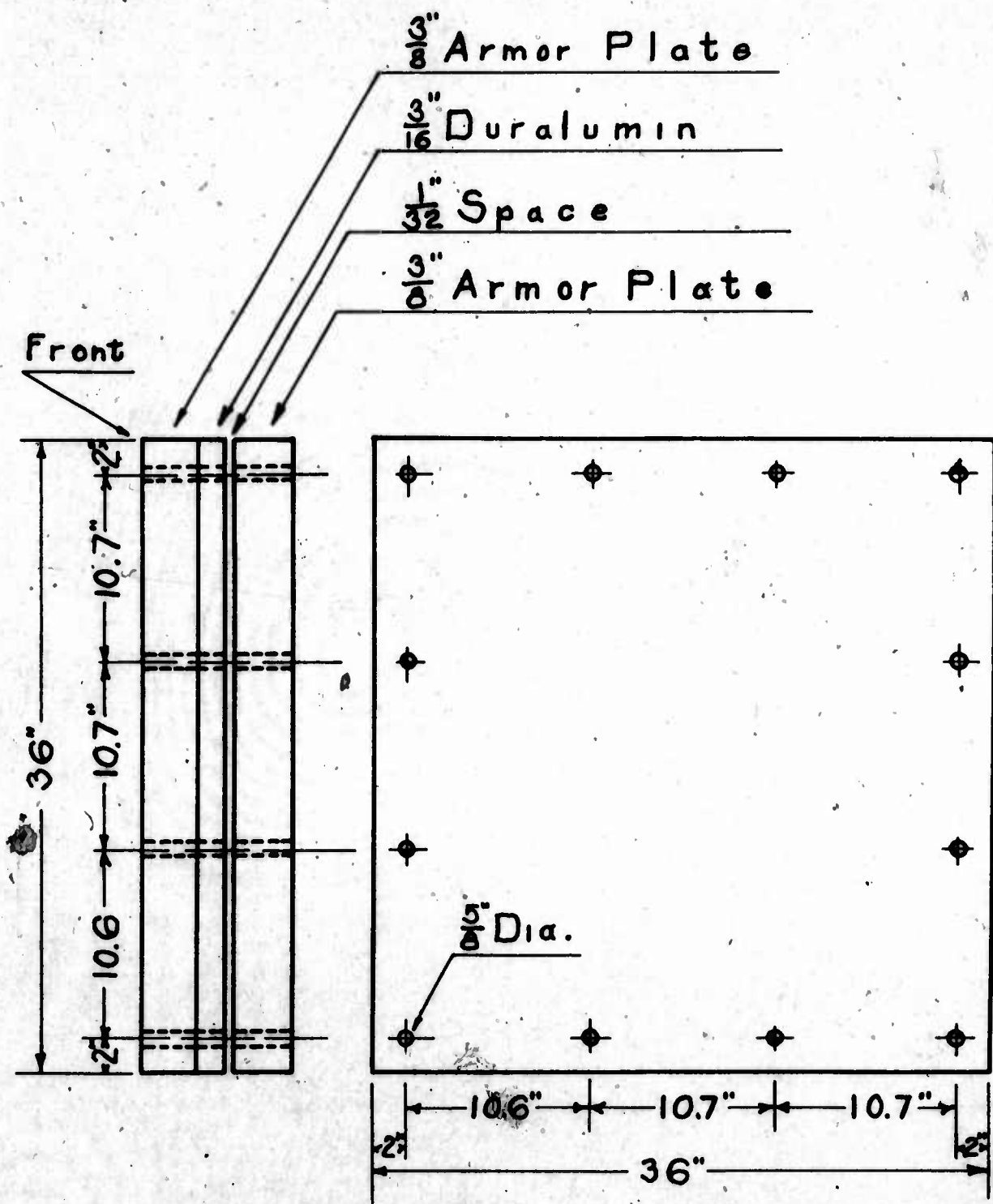
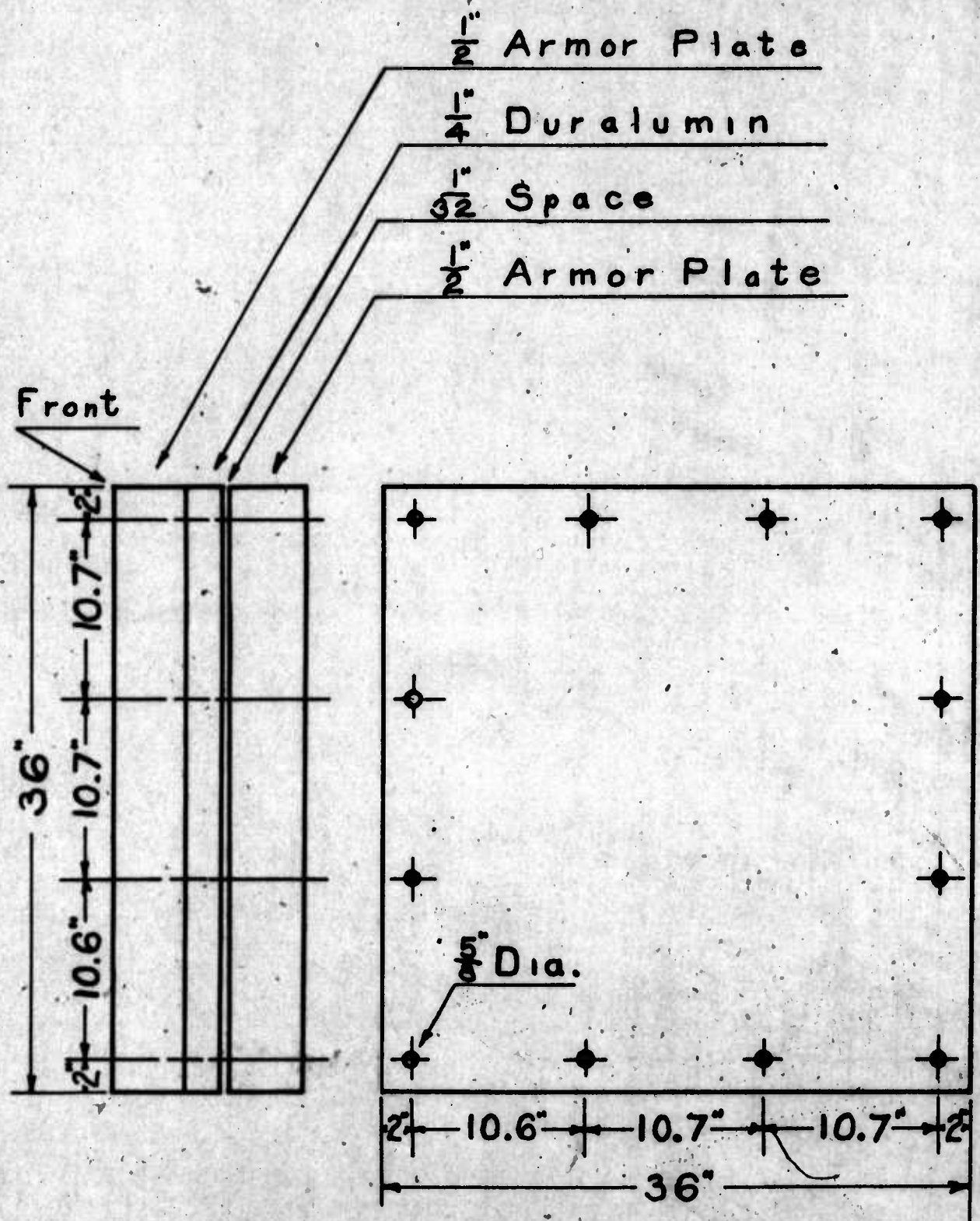


FIG. 3

Plan of L3



L

FIG. 5

4

3

2

5

6

710-350

REAR FACE - FRONT ARMOR PLATE

INCHES
0 1 2 3 4 5 6 7 8 9 10 11 12
FEDERAL BUREAU OF INVESTIGATION
WASHINGTON, D. C. 20535

FIG 4

L

710-349

FRONT FACE - FRONT ARMOR PLATE

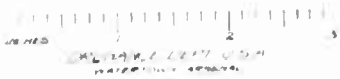
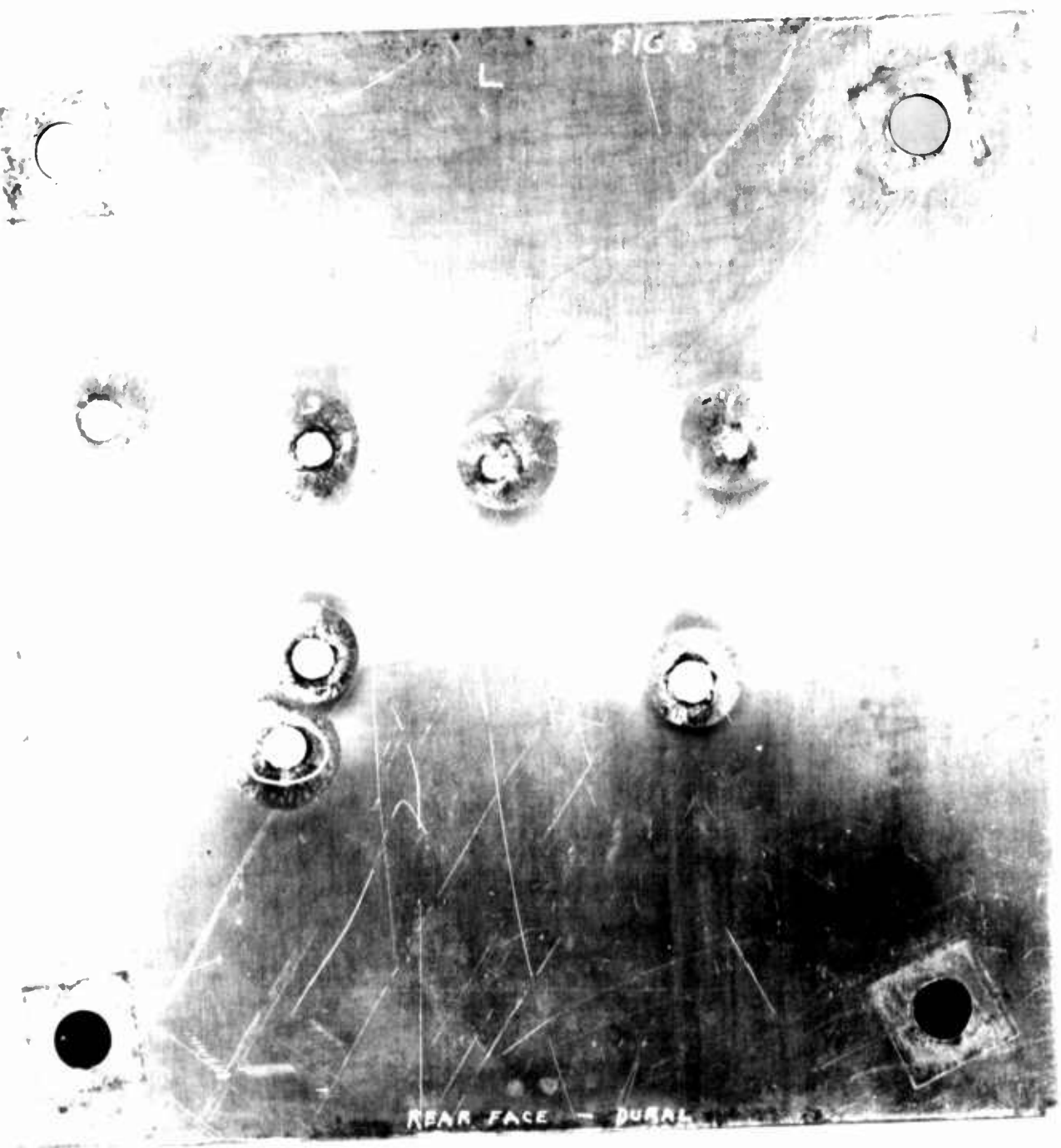
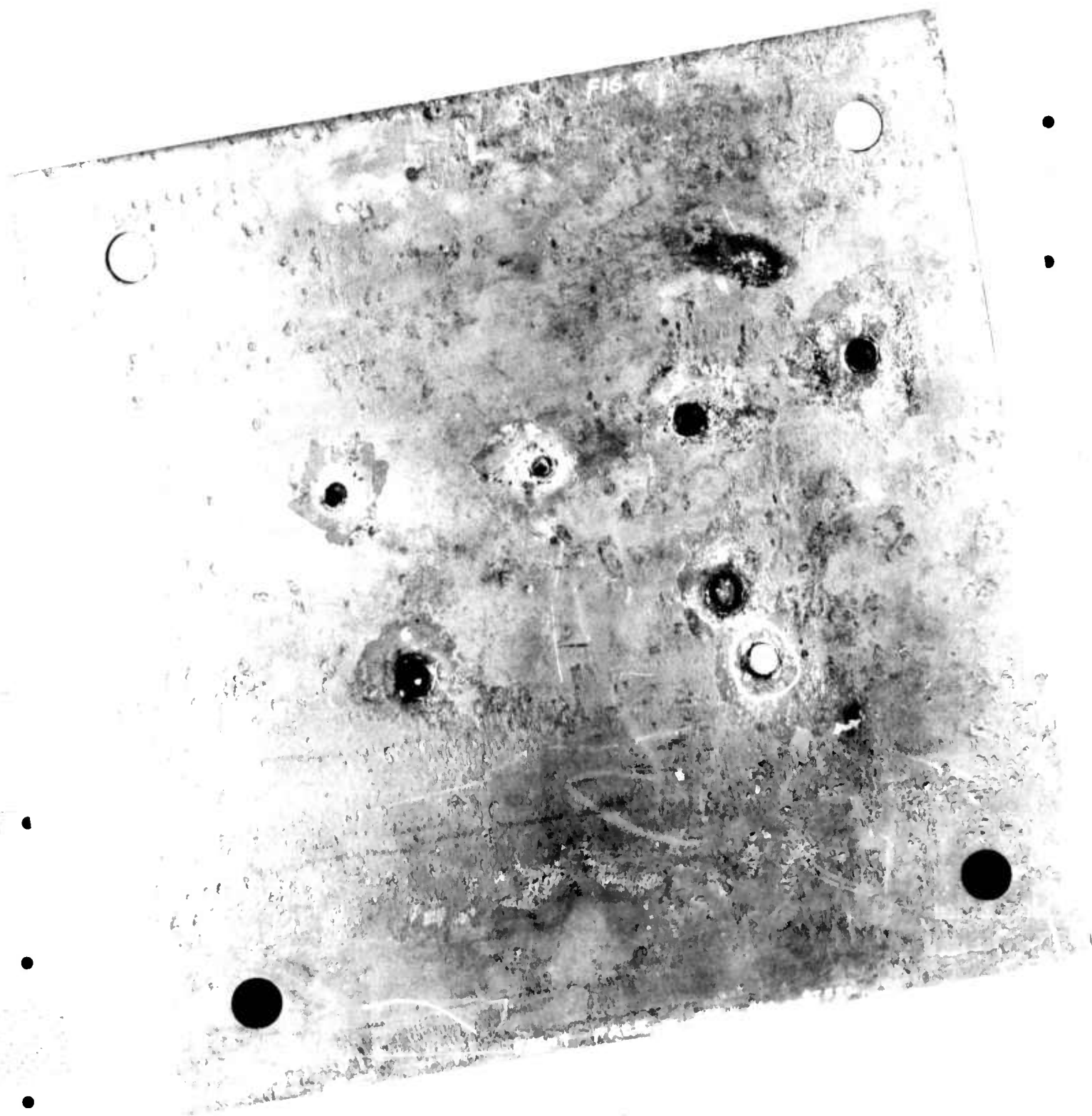


FIG 3

L

REAR FACE - DURAL





F16.8



REAR FACE - NI-MO STEEL

WATERTOWN LAMINATED

2 PLATE L-3

5 1/4" THICK

FACE

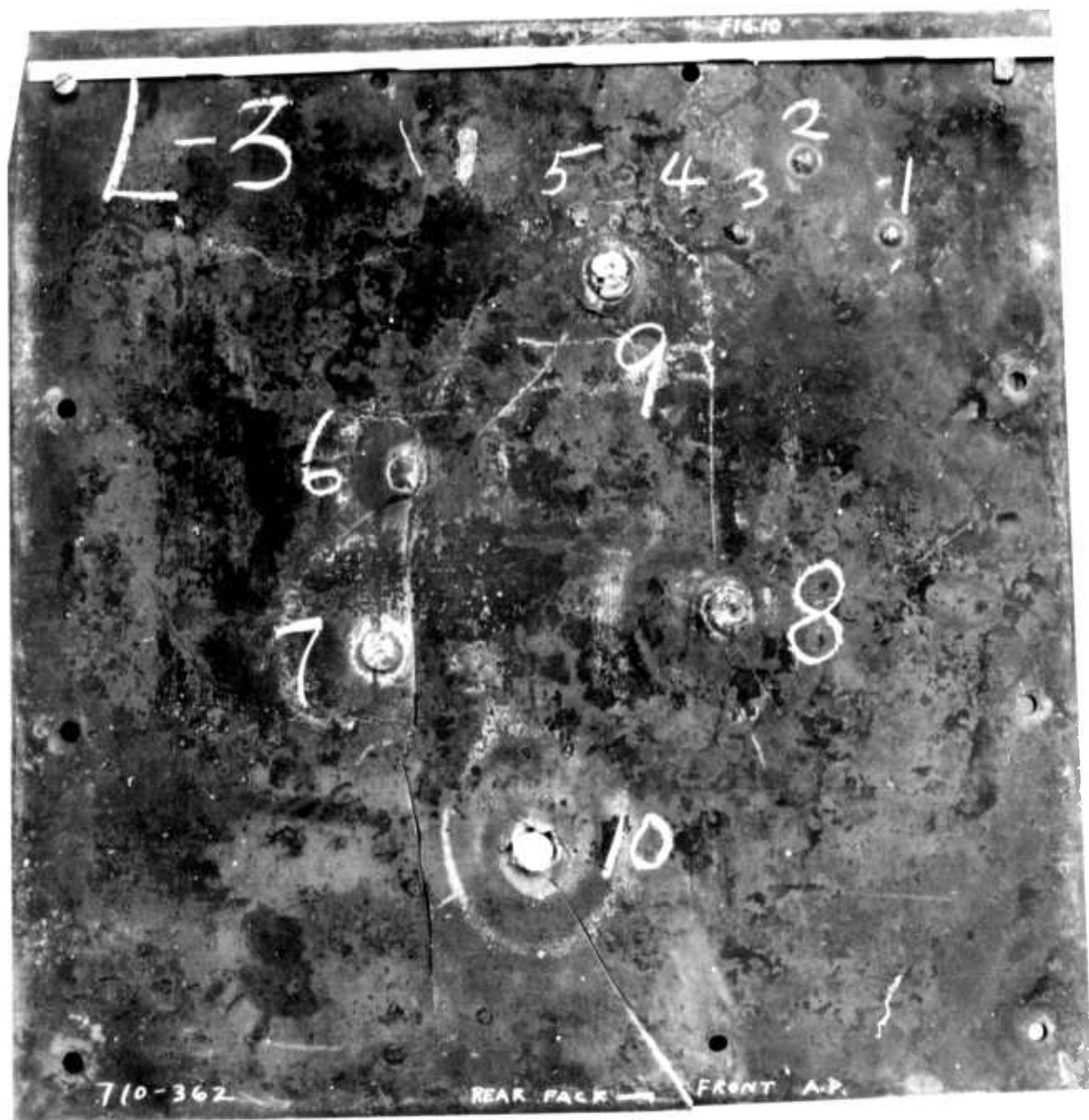
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7

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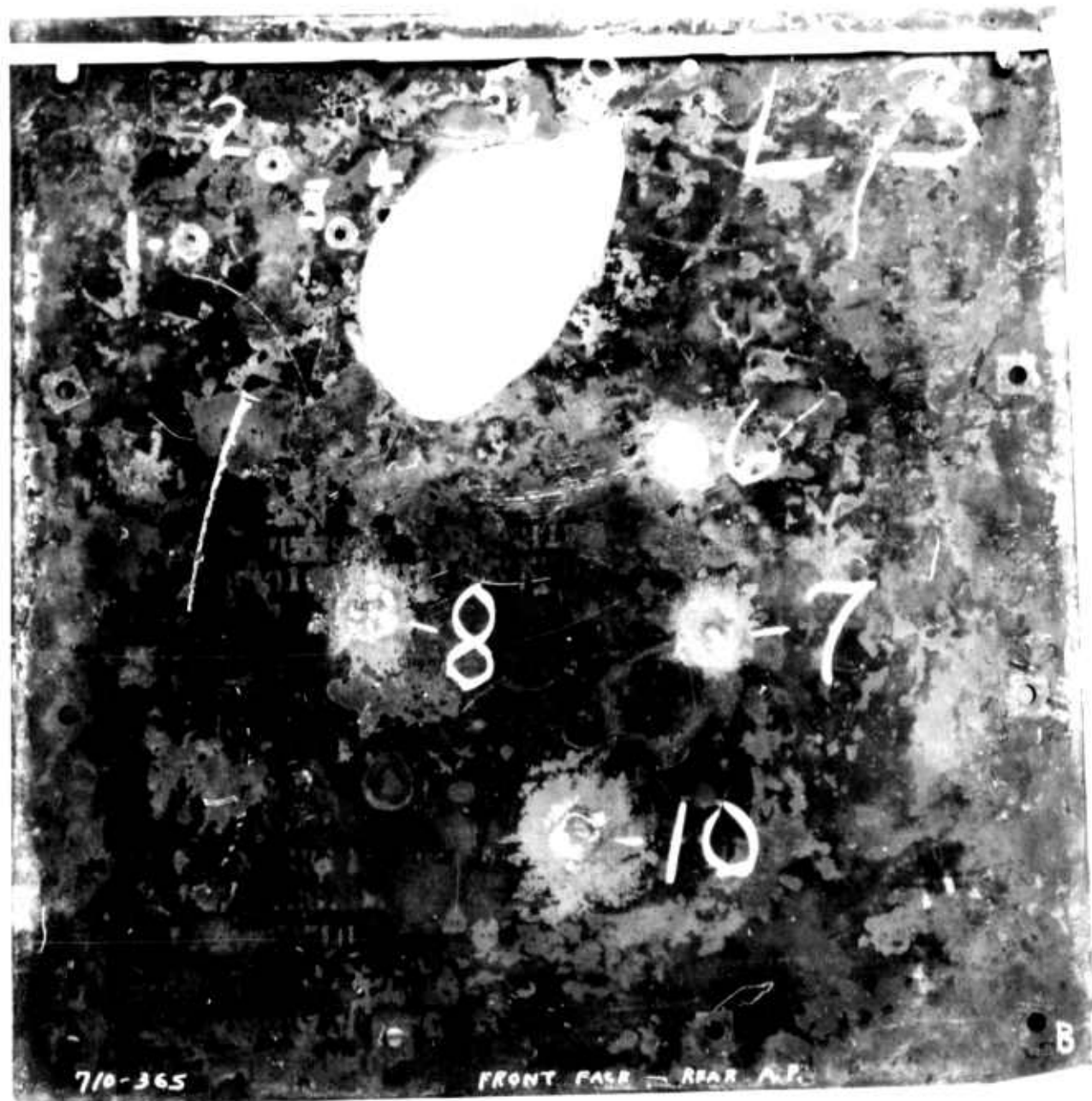
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4/38

710065

BEAR FACE

DURAL



710-365

FRONT FACE - REAR A.P.

B

WATERTOWN
LAMINATED
PLATE L3

1/4 THICK
BACK

7 →

10 →

5 ↓
6 ↓

4 ↓

2 ↓

3 ←

1 ←

8 ←

710-366

REAR FACE - REAR A.P.

Figure 14

Typical microstructures of heat treated armor plate used in the construction of laminated plate.

- (1) Fine martensite-troostite. 1% Nital Etch, X1000

MA-1368

- (2) Crack seems to follow grain boundaries in area near penetration of 37 mm. shell.
1% Nital Etch, X1500

MA-1379

- (3) Even distribution of fairly small non-metallic inclusions. Unetched, X100.

MA-1223

- (4) Extreme banding of carbides.
Murakami Etch, X250

MA-1366

FIGURE 14.



(3)

x100

(4)

x250

W A 632-1572